Jet Propulsion Laboratory
California Institute of Technology

Show Me the Planets!
NASA Exoplanet Exploration

The Search for Habitable Worlds and for Life Beyond the Solar System

Dr. Gary H. Blackwood

Manager, NASA Exoplanet Exploration Program
Jet Propulsion Laboratory, California Institute of Technology

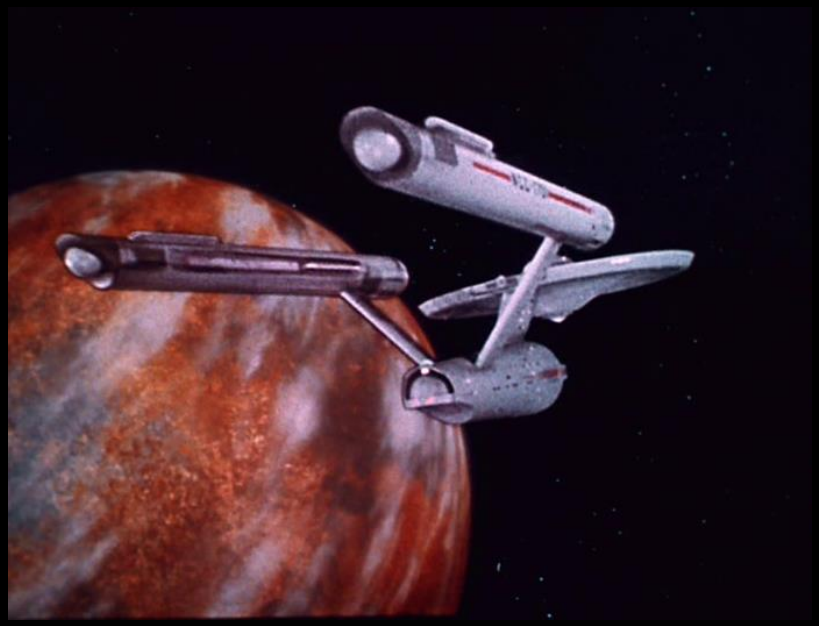
December 12, 2017

Aerospace and Defense Forum, San Fernando Chapter, Sherman Oaks, CA

Artist concept of Kepler-16b

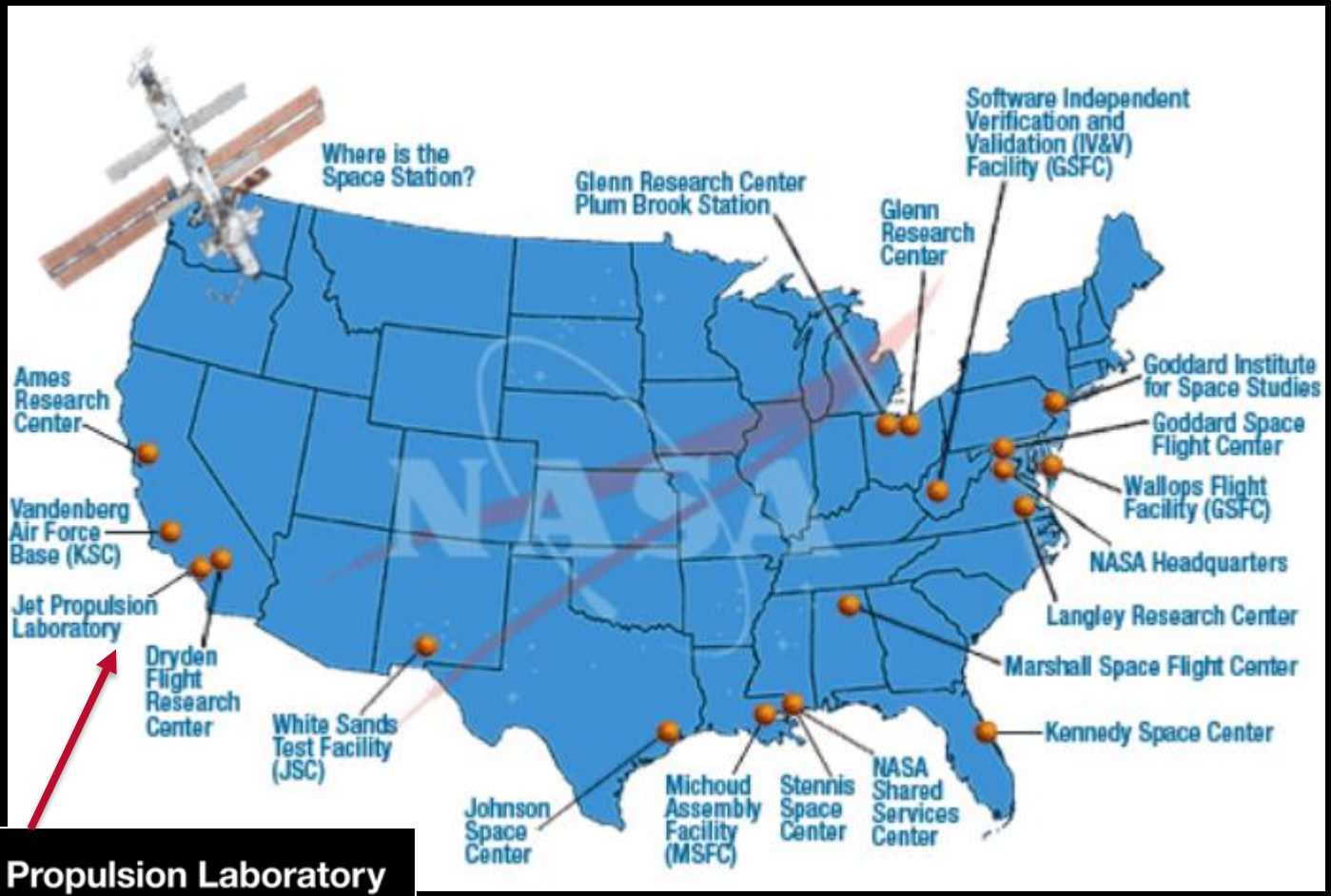
What is an Exoplanet?

Exoplanet – a planet that orbits another star



Credit: Paramount

NASA Centers and Facilities



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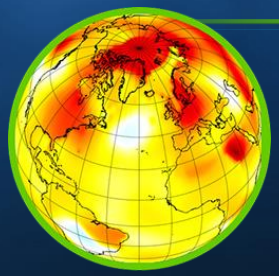
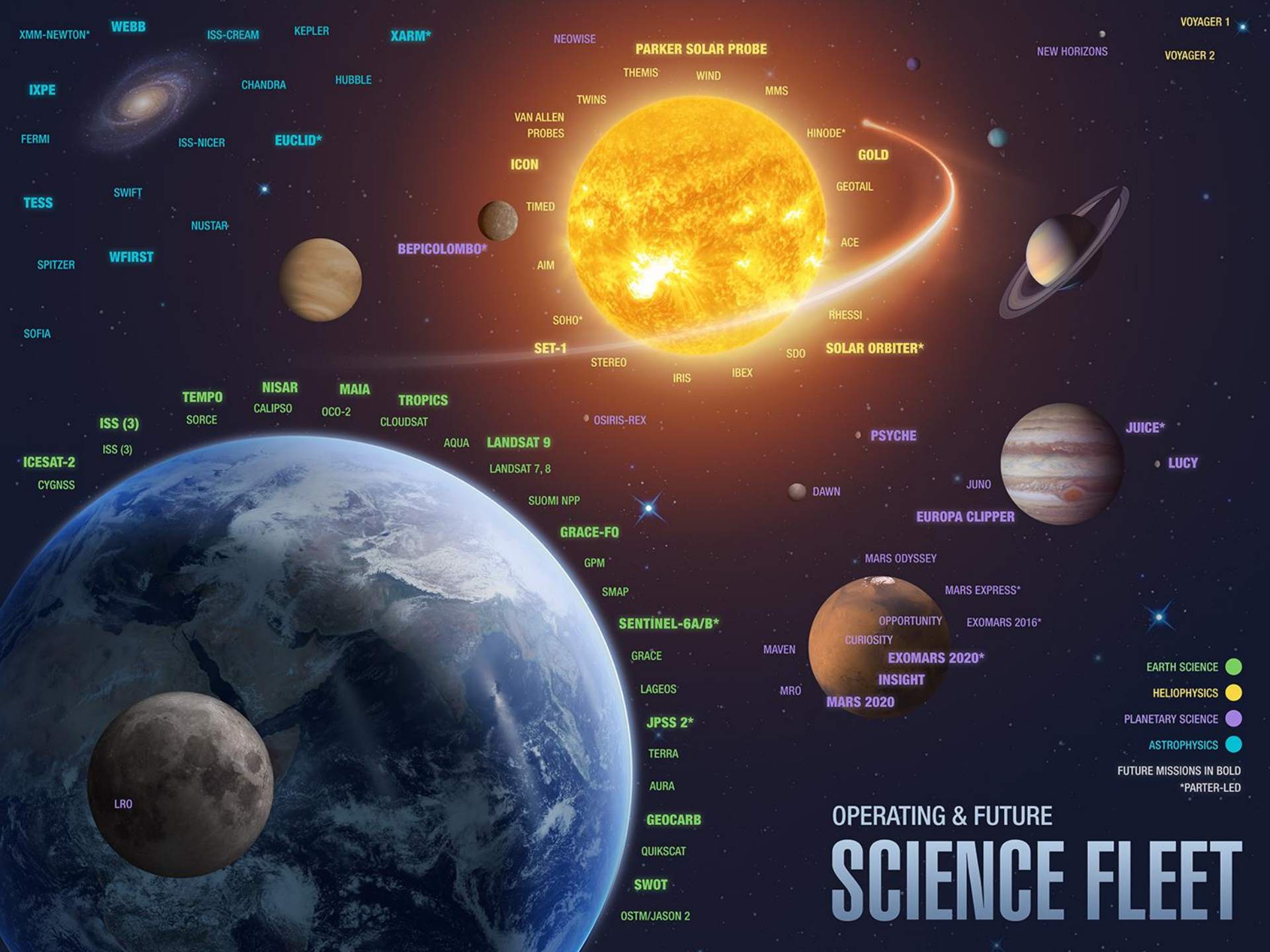
KEY SCIENCE THEMES

Discovering the Secrets of the Universe

Searching for Life Elsewhere



Safeguarding and Improving Life on Earth



OPERATING & FUTURE

SCIENCE FLEET

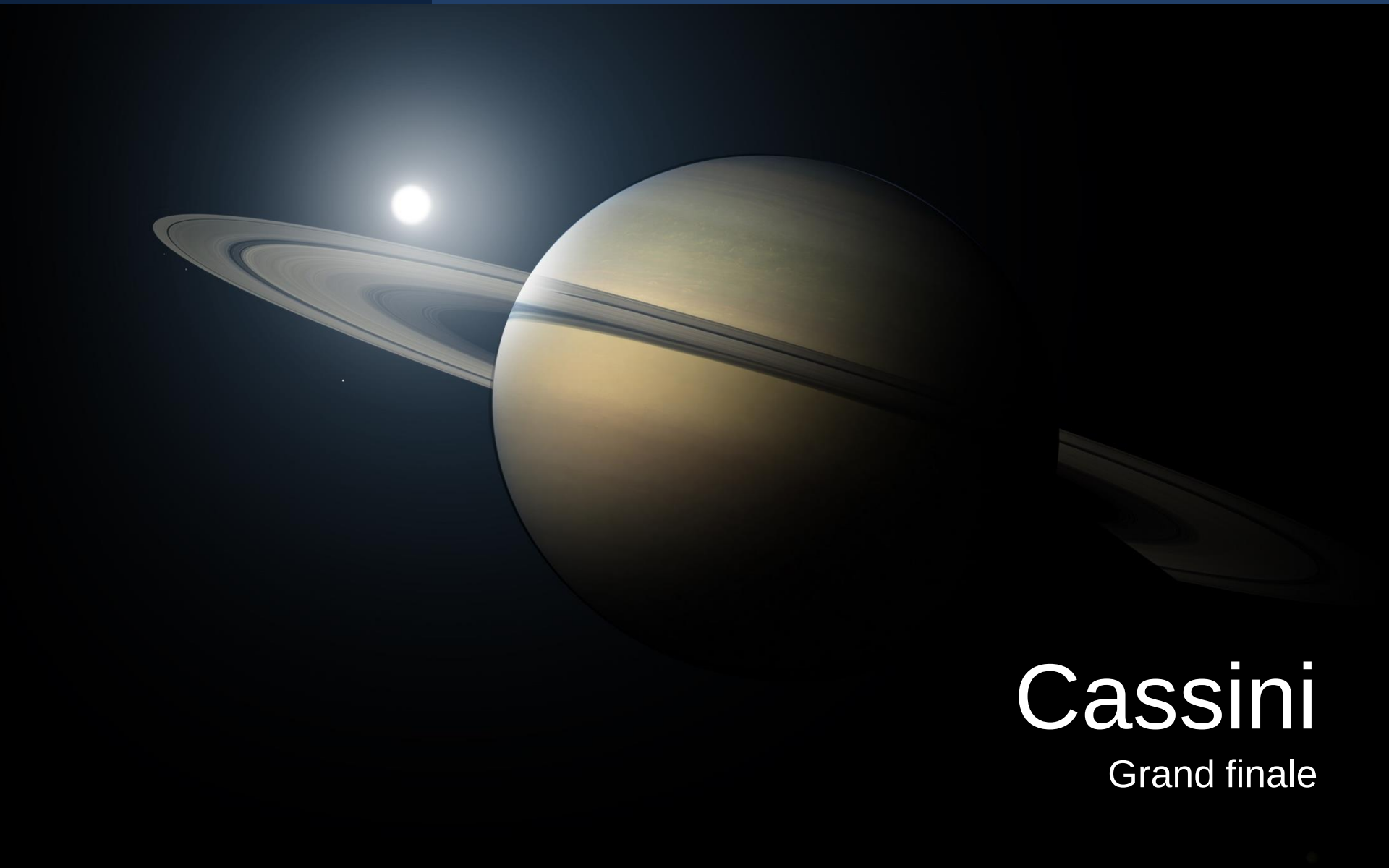
SEARCHING FOR LIFE ELSEWHERE

MSL Curiosity

SEARCHING FOR LIFE ELSEWHERE

Vera Rubin Ridge

SEARCHING FOR LIFE ELSEWHERE



Cassini

Grand finale

Exoplanet Exploration

Credit: PHL@UPR, Arecibo, ESA/Hubble, NASA

"All These Worlds are Yours…"

- Arthur C. Clarke, 2010: Odyssey Two

Credit: SETI Institute

NASA Exoplanet Exploration Program

Astrophysics Division, NASA Science Mission Directorate

NASA's search for habitable planets and life beyond our solar system

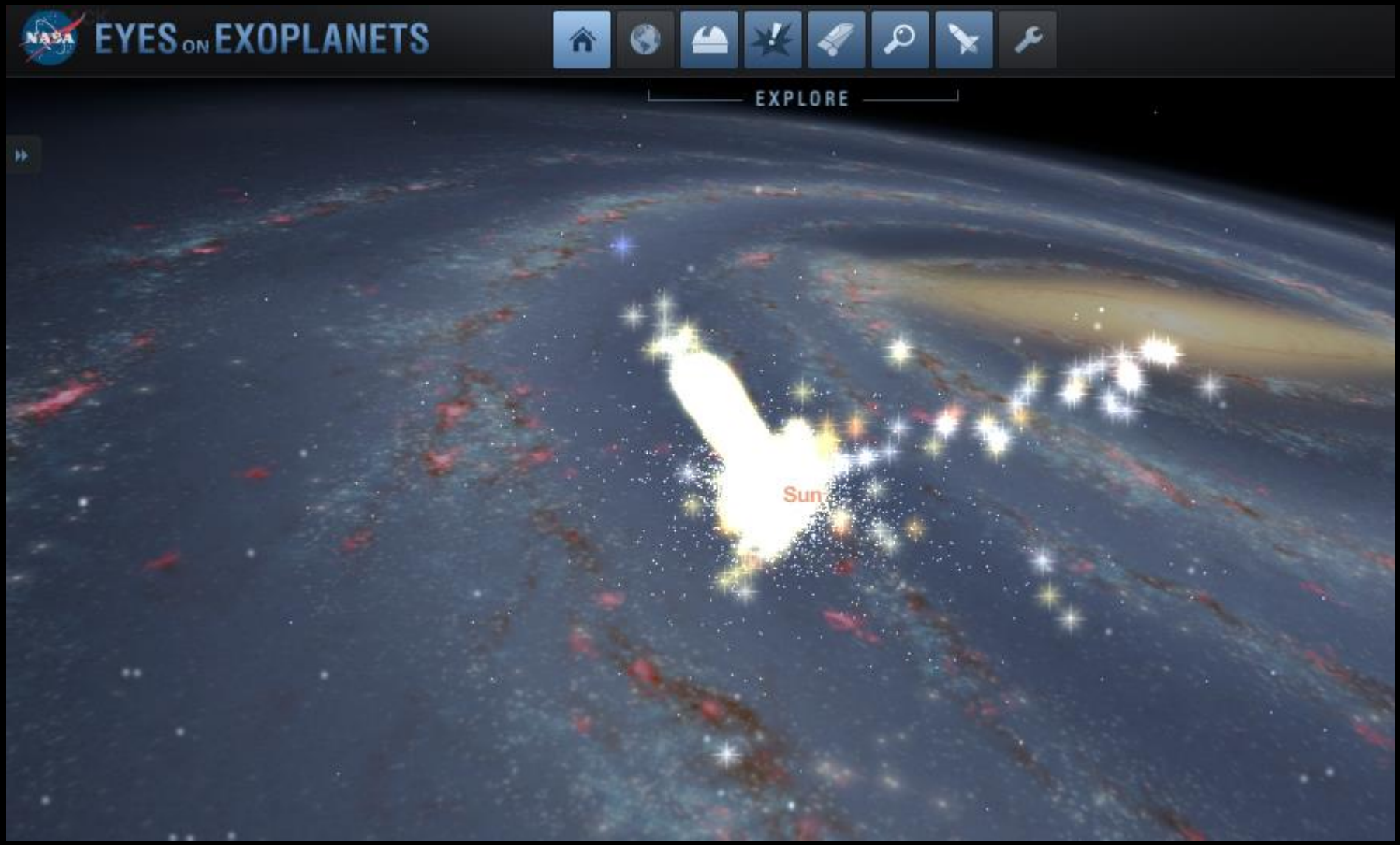
Program purpose described in
2014 NASA Science Plan

1. Discover planets around other stars
2. Characterize their properties
3. Identify candidates that could harbor life

https://exoplanets.nasa.gov

Where are the Exoplanets?

Visualization from *Eyes on Exoplanets*

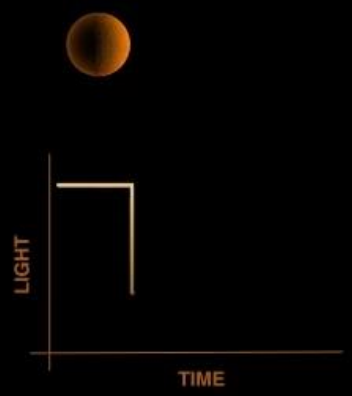


How Do We Find Exoplanets?

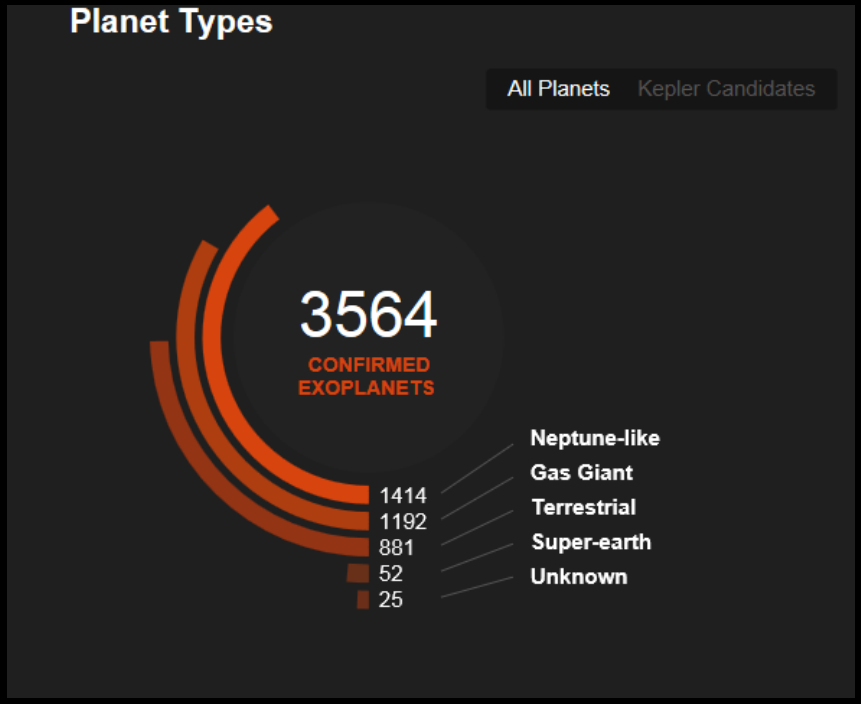
Doppler Spectroscopy or Radial Velocity Method

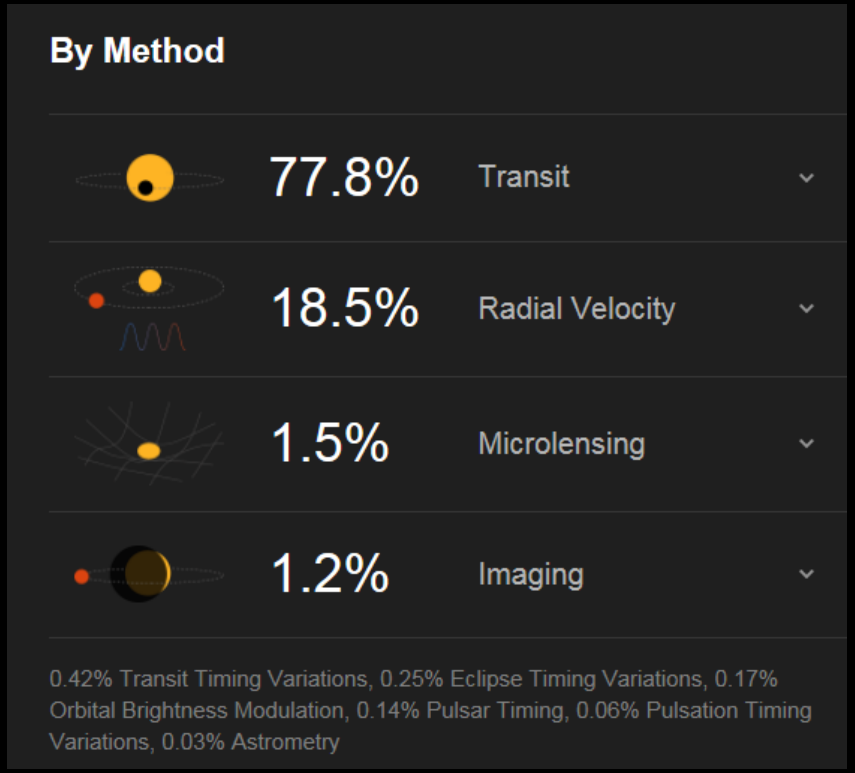
How Do We Find Exoplanets?

Transit Method

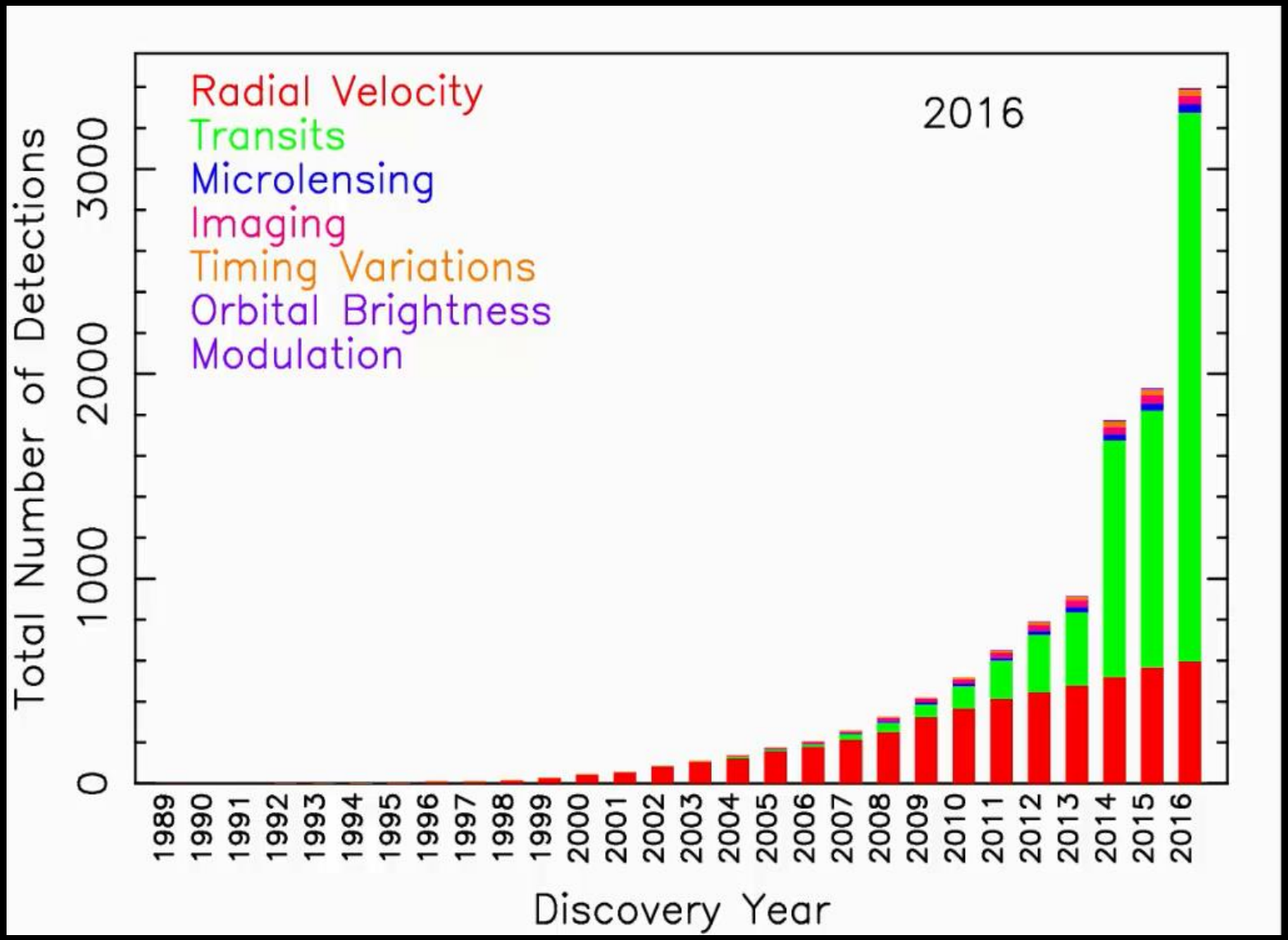


Exoplanets by the Numbers



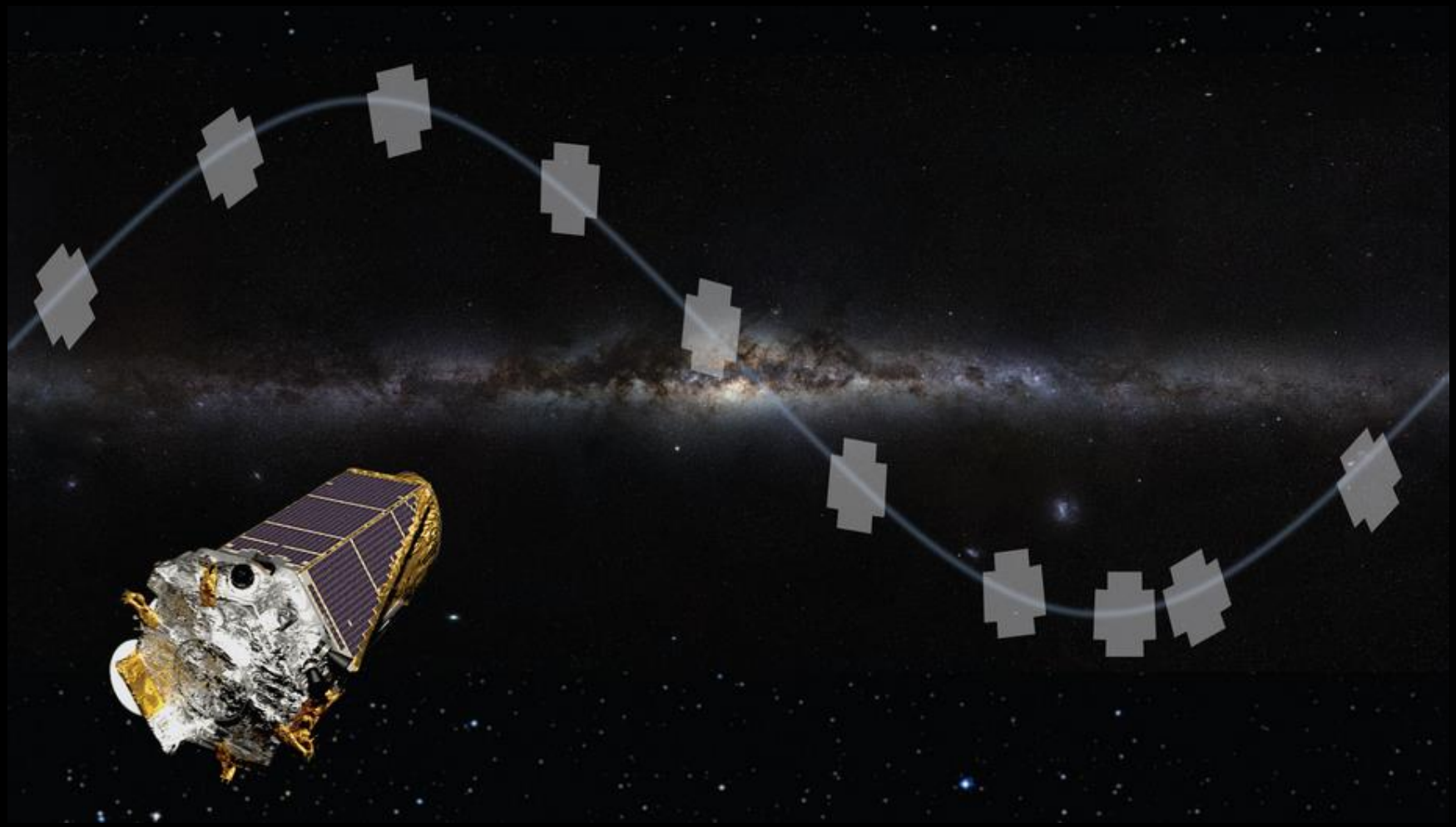


Confirmed Exoplanets versus Time



Kepler K2

Extending the Power of Kepler to the Ecliptic



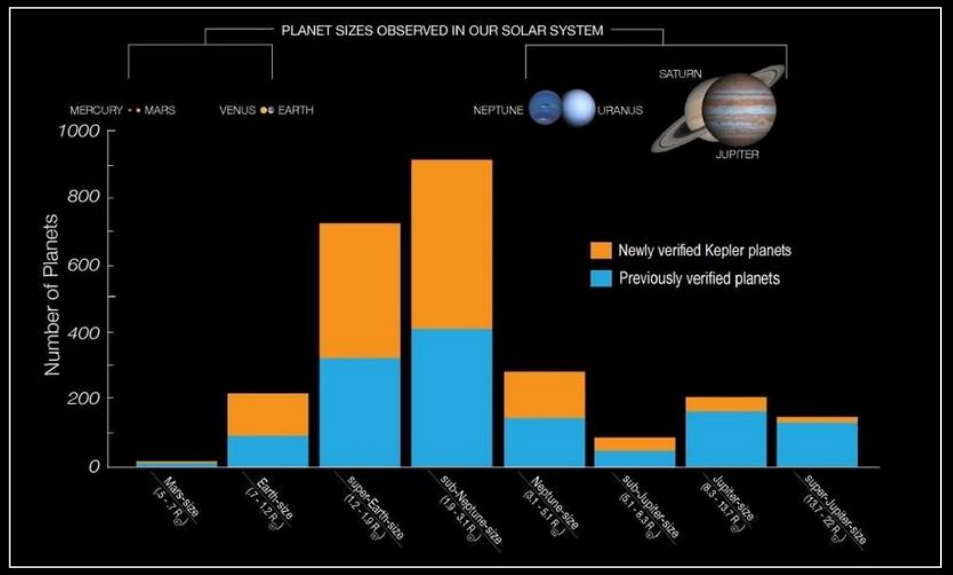
Credit: NASA/Ames Research Center/W. Stenzel

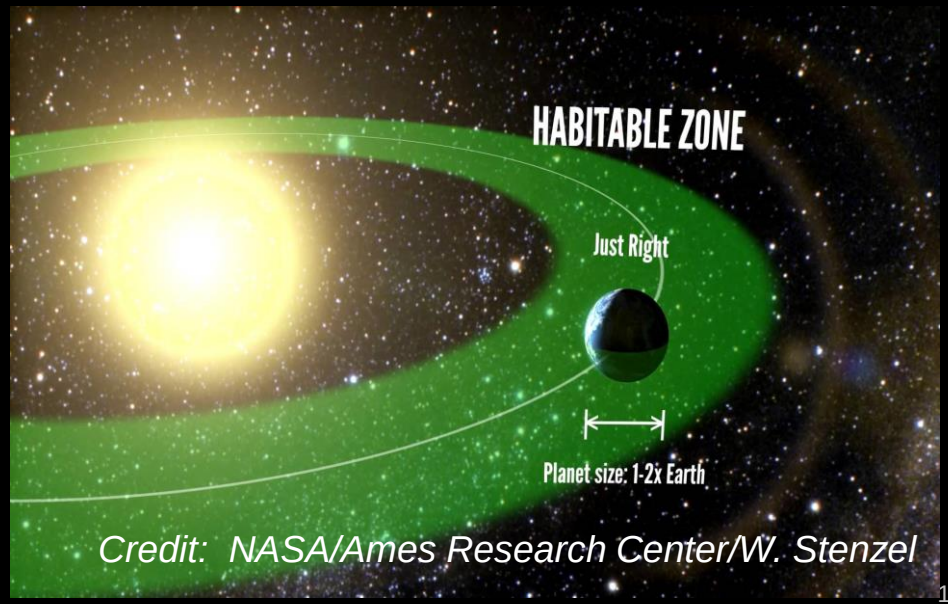
Three Key Kepler Results

1. On average there is at least one planet for each of the stars in the night sky

2. Small planets are the most common type in the Galaxy

3. Earth-sized (0.5 to 2 Earth radii) planets in the Habitable Zone are common





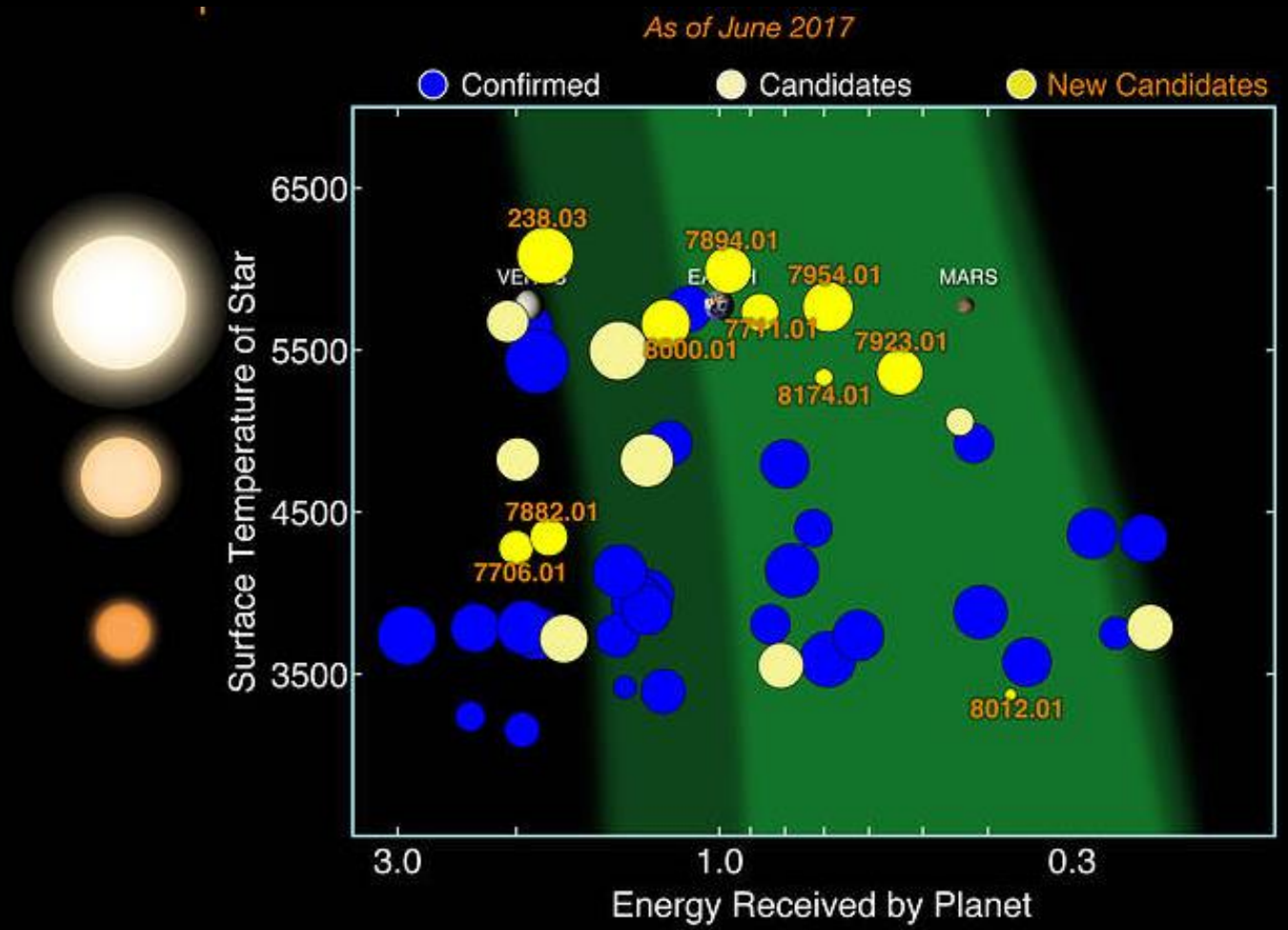
Credit: NASA/Ames Research Center/W. Stenzel

A Familiar Habitable Zone

Credit: Luc Forsyth

Kepler Habitable Zone Planets

As of June 2017



Credit: NASA/Ames Research Center/W. Stenzel

Seven Planets Above the Fold: Trappist-1

"All the News That's Fit to Print"

The New York Times

Late Edition
Today, patchy morning fog, partly sunny, warm, high 64. Tonight, mostly cloudy, mild, low 52. Tomorrow, clouds and sunshine, showers, high 66. Weather map is on Page B9.

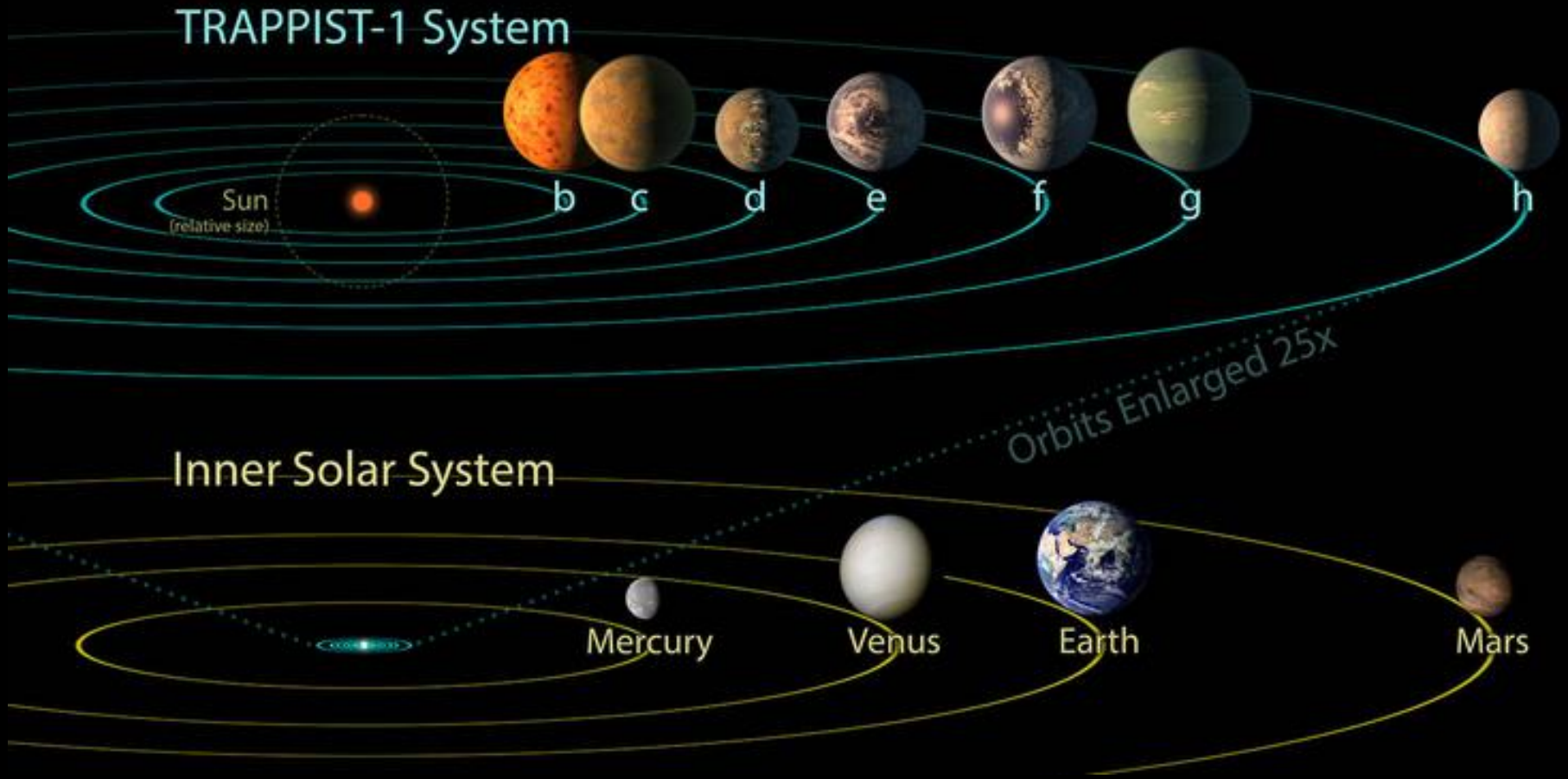
VOL. CLXVI ... No. 57,517 © 2017 The New York Times Company NEW YORK, THURSDAY, FEBRUARY 23, 2017 $2.50

JPL-CALTECH/NASA

A rendering of newly discovered Earth-size planets orbiting a dwarf star named Trappist-1 about 40 light-years from Earth. Some of them could have surface water.

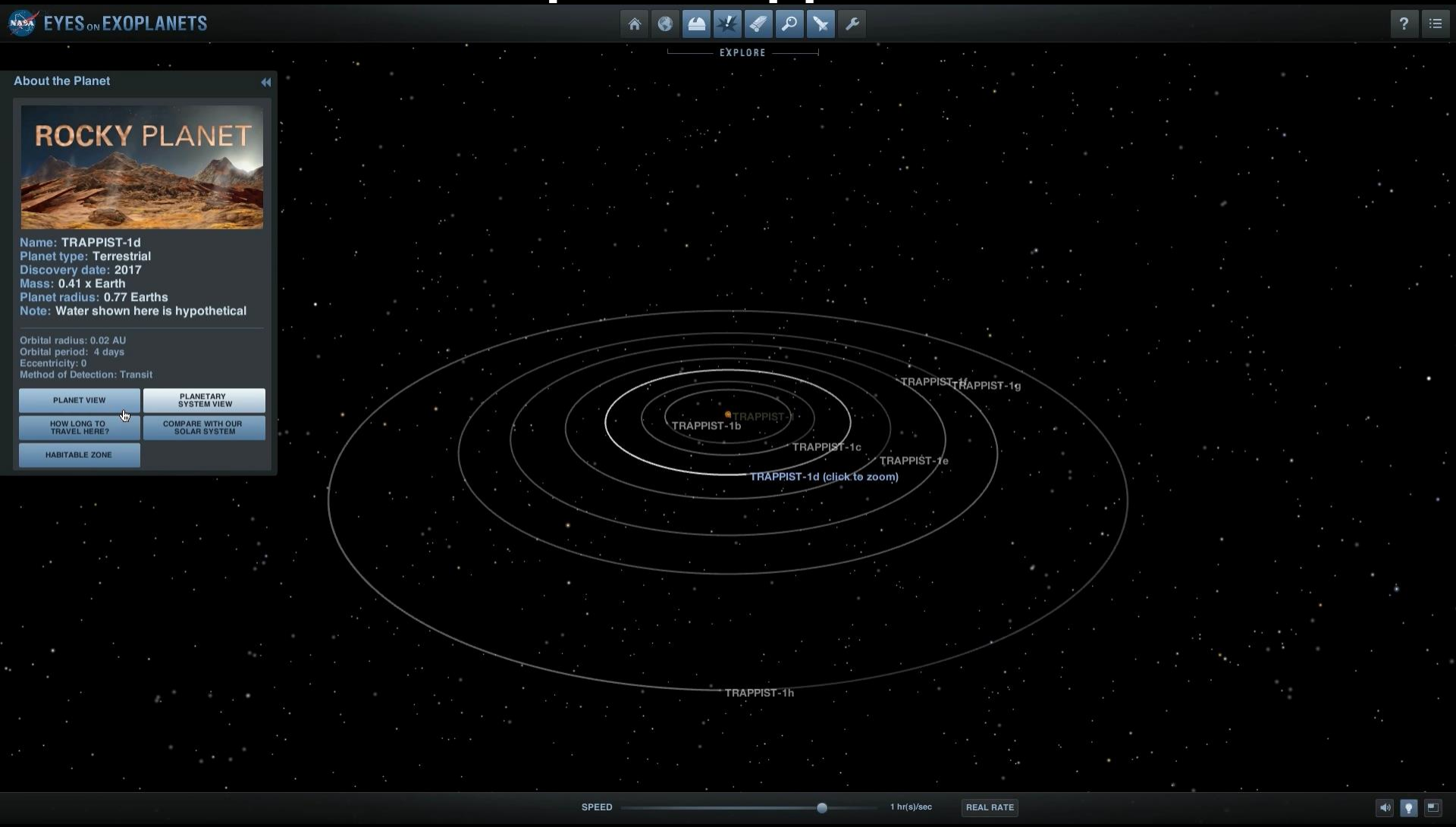
Trappist-1 Discovery

The Richest Set of Earth-sized Planets Ever Found



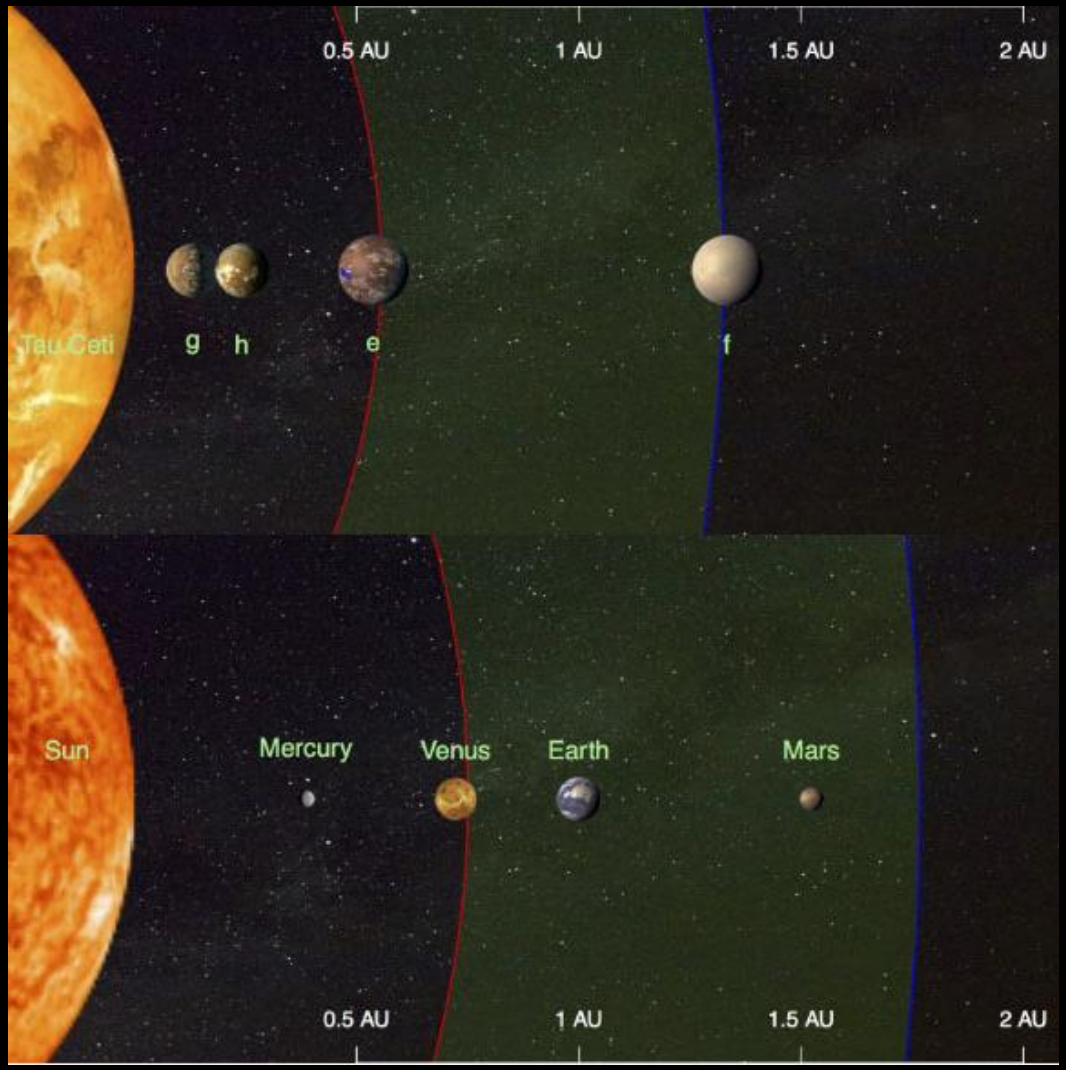
Credit: NASA/JPL

How About a Trip to Trappist-1?

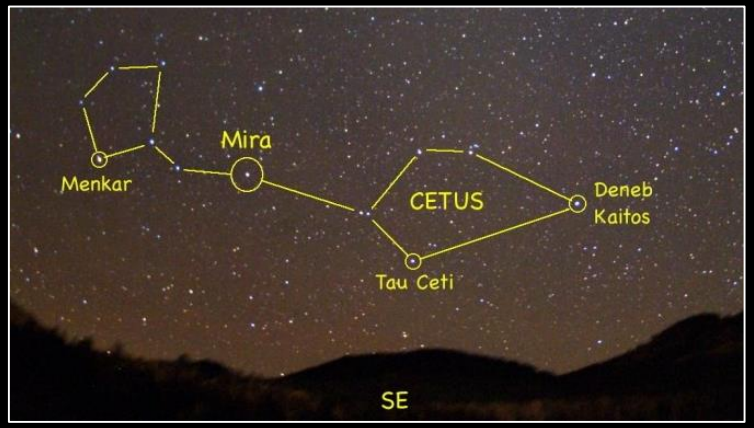


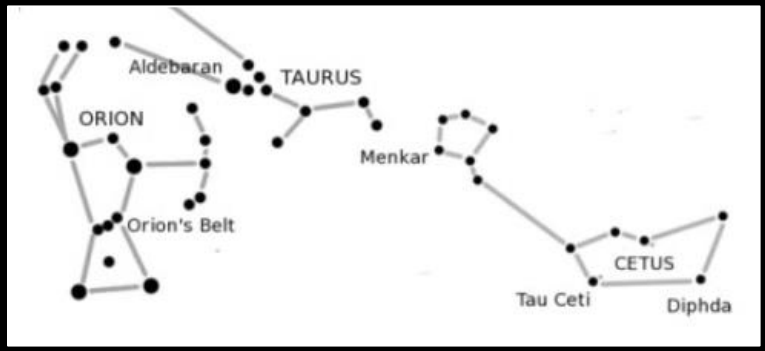
Tau Ceti e

Likely Rocky Super-Earth Orbiting a Nearby Sun-like Star



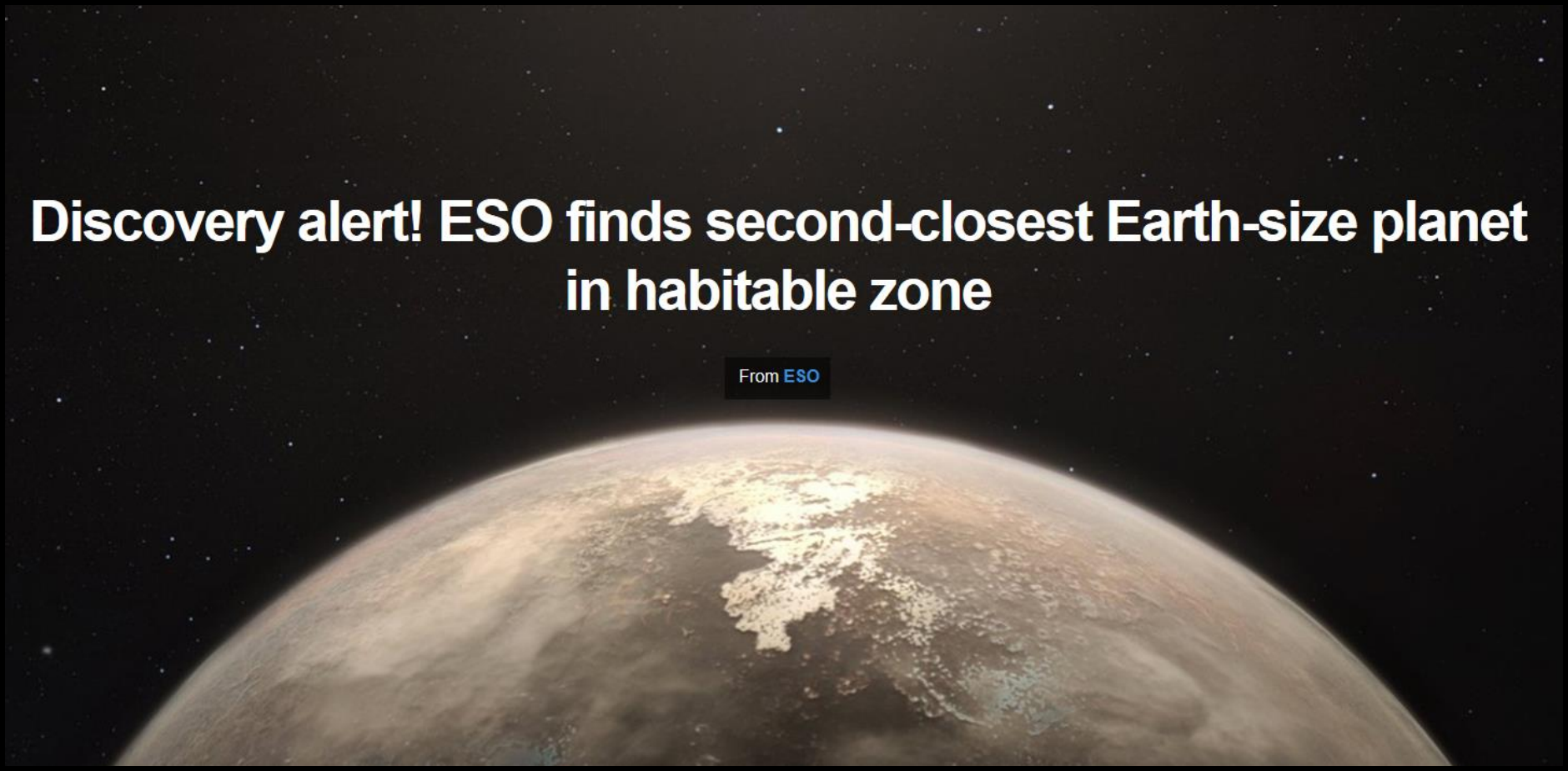
Credit: F. Feng, University of Hertfordshire





Second-closest Earth-sized Planet

Ross 128 b

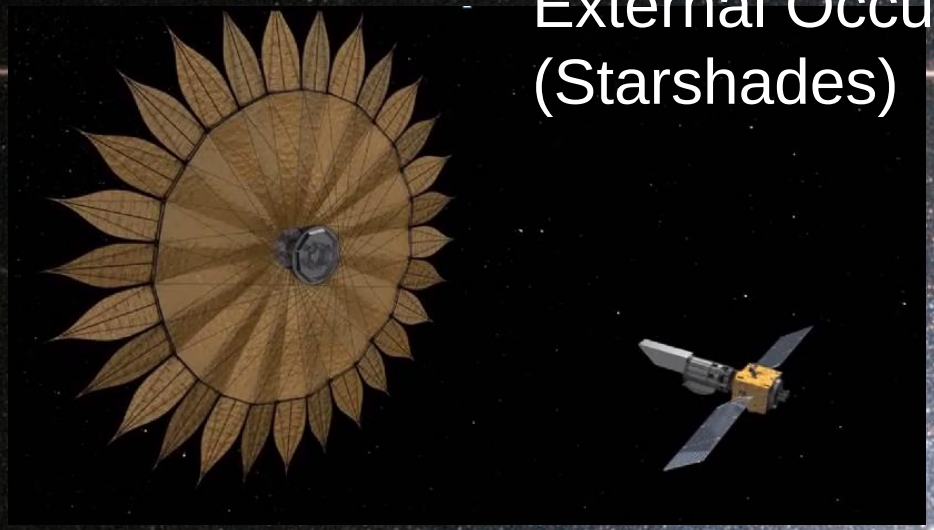


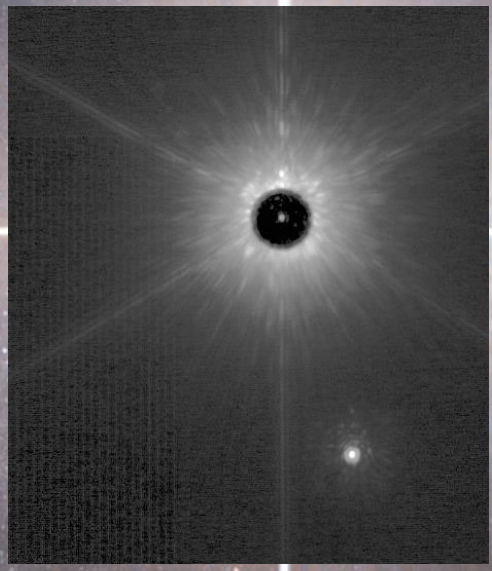
Credit: ESO

Starlight Suppression

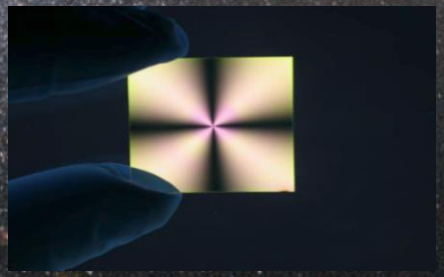
The Key to the Search for Life on Earth-sized Exoplanets

External Occulters
(Starshades)



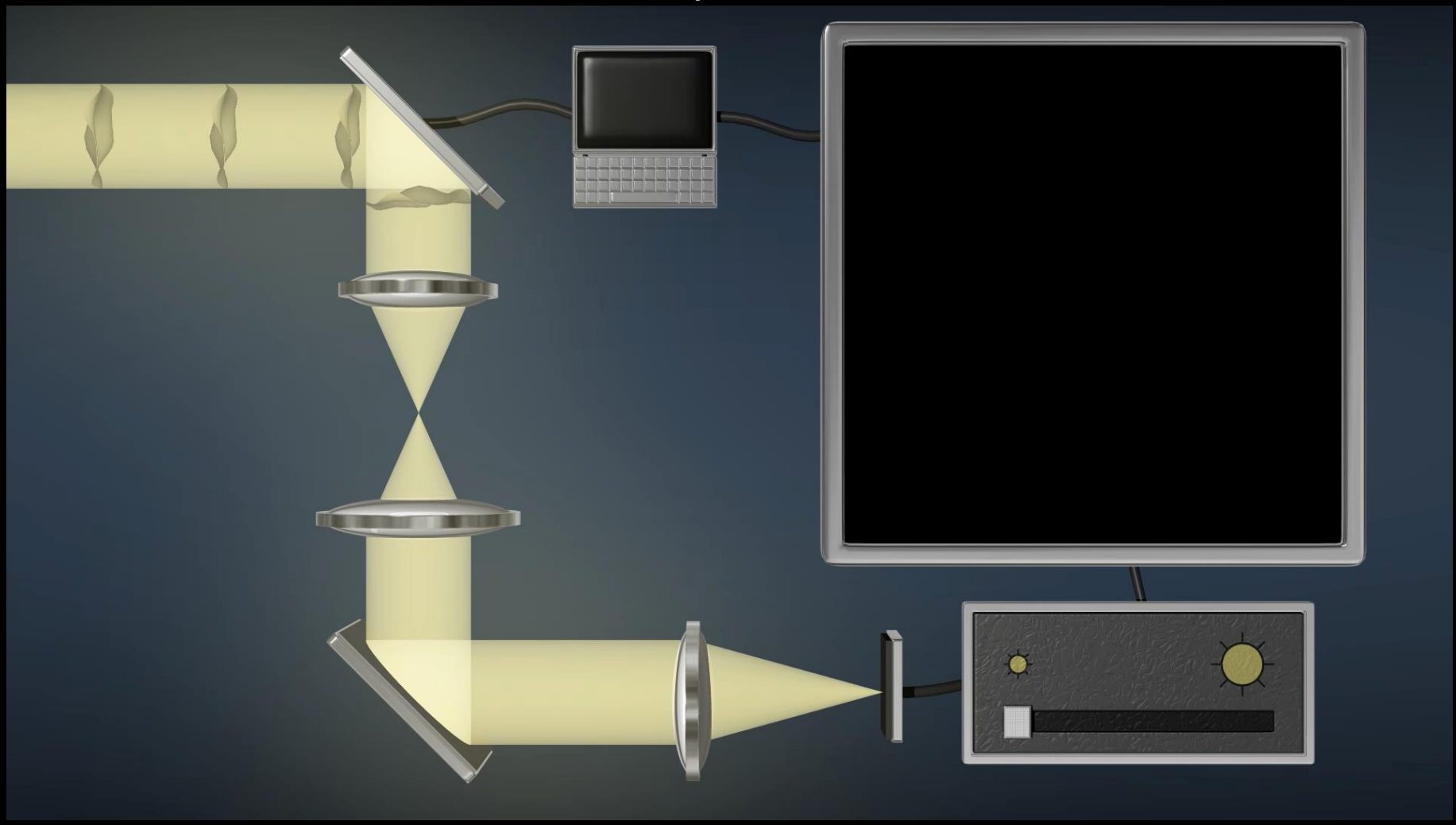


Internal Occulters
(Coronagraphs)



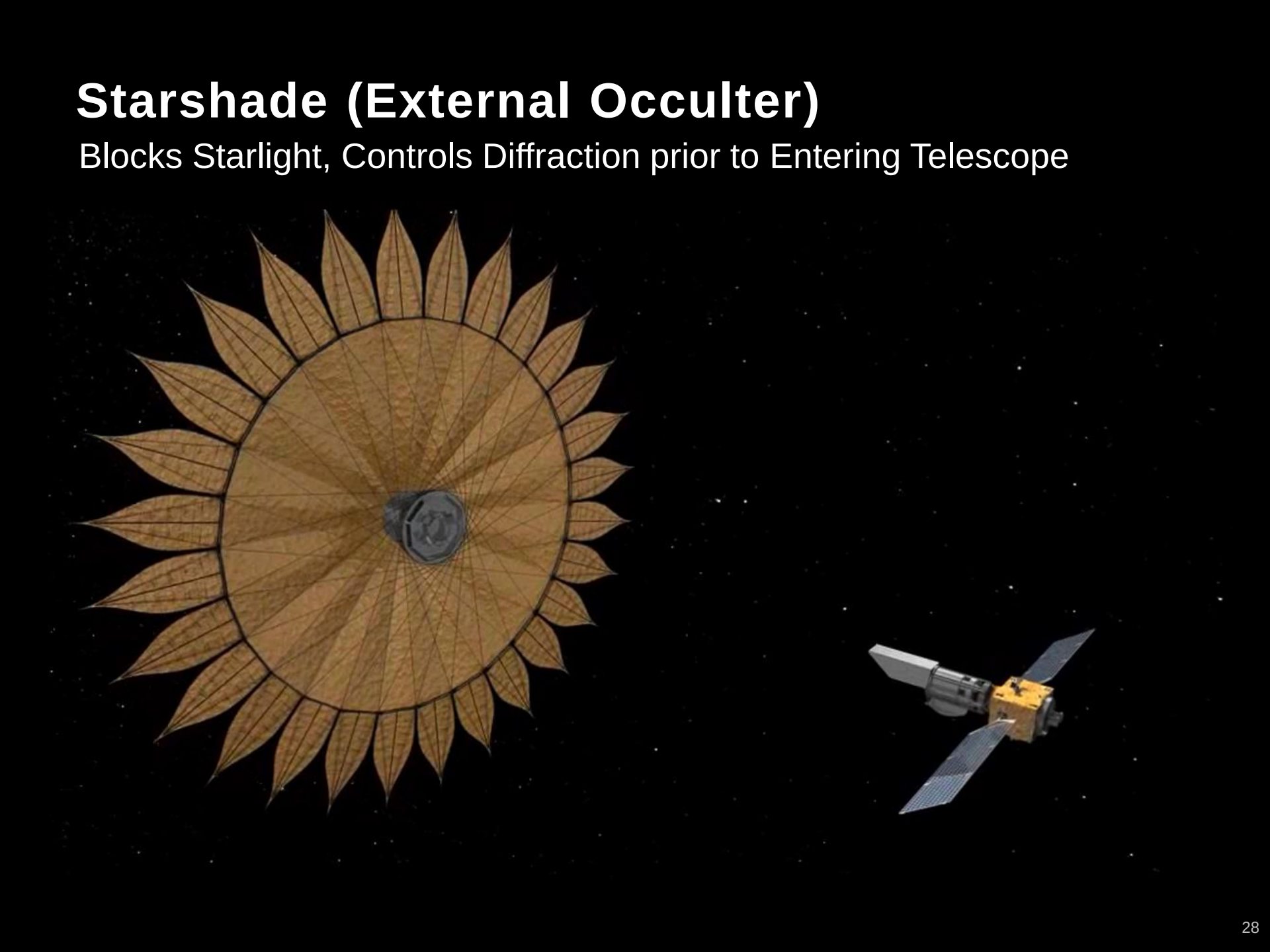
Internal Coronagraph

Controls Diffraction to Reveal Exoplanets in “Dark Hole”



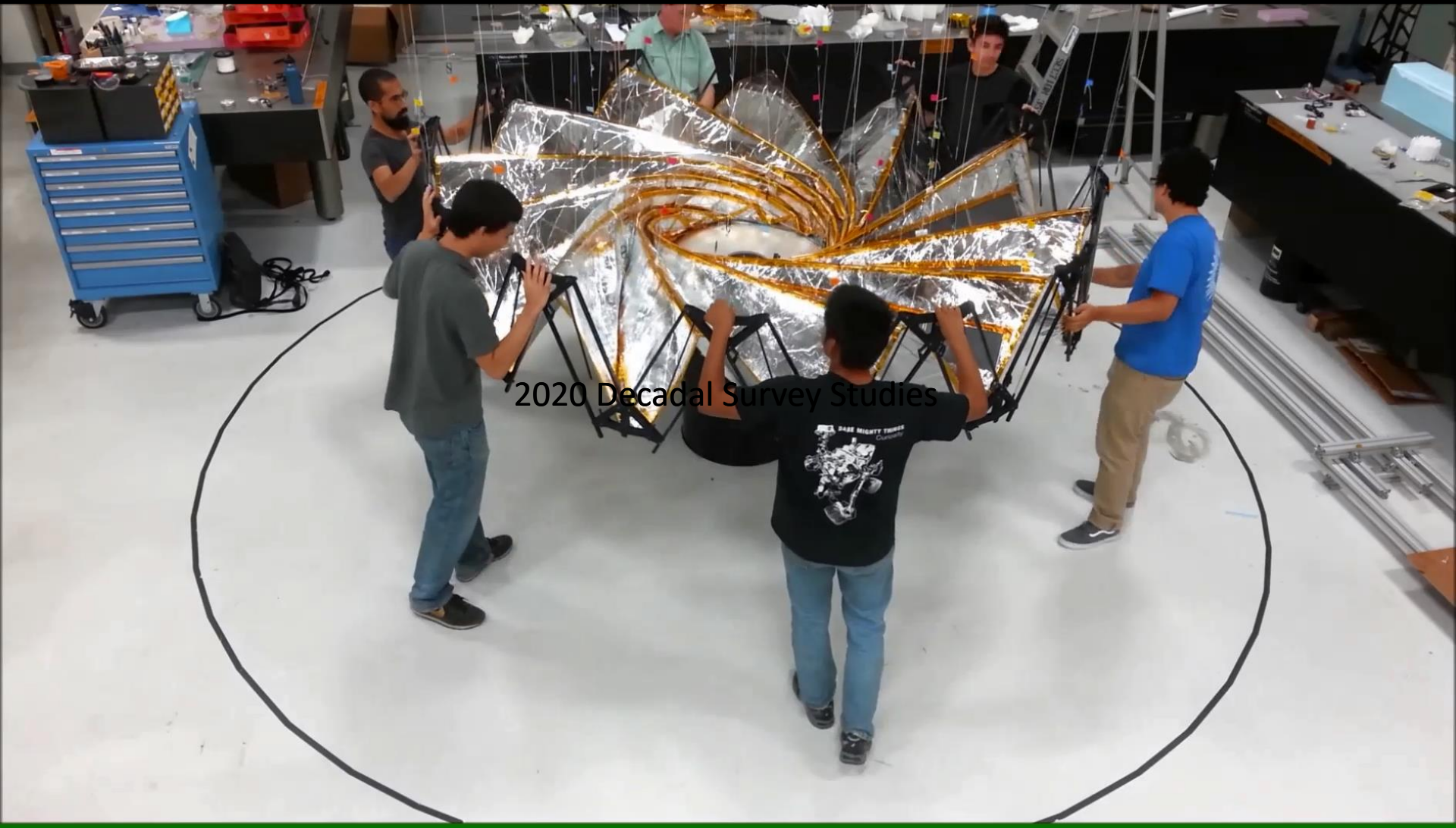
Starshade (External Occulter)

Blocks Starlight, Controls Diffraction prior to Entering Telescope

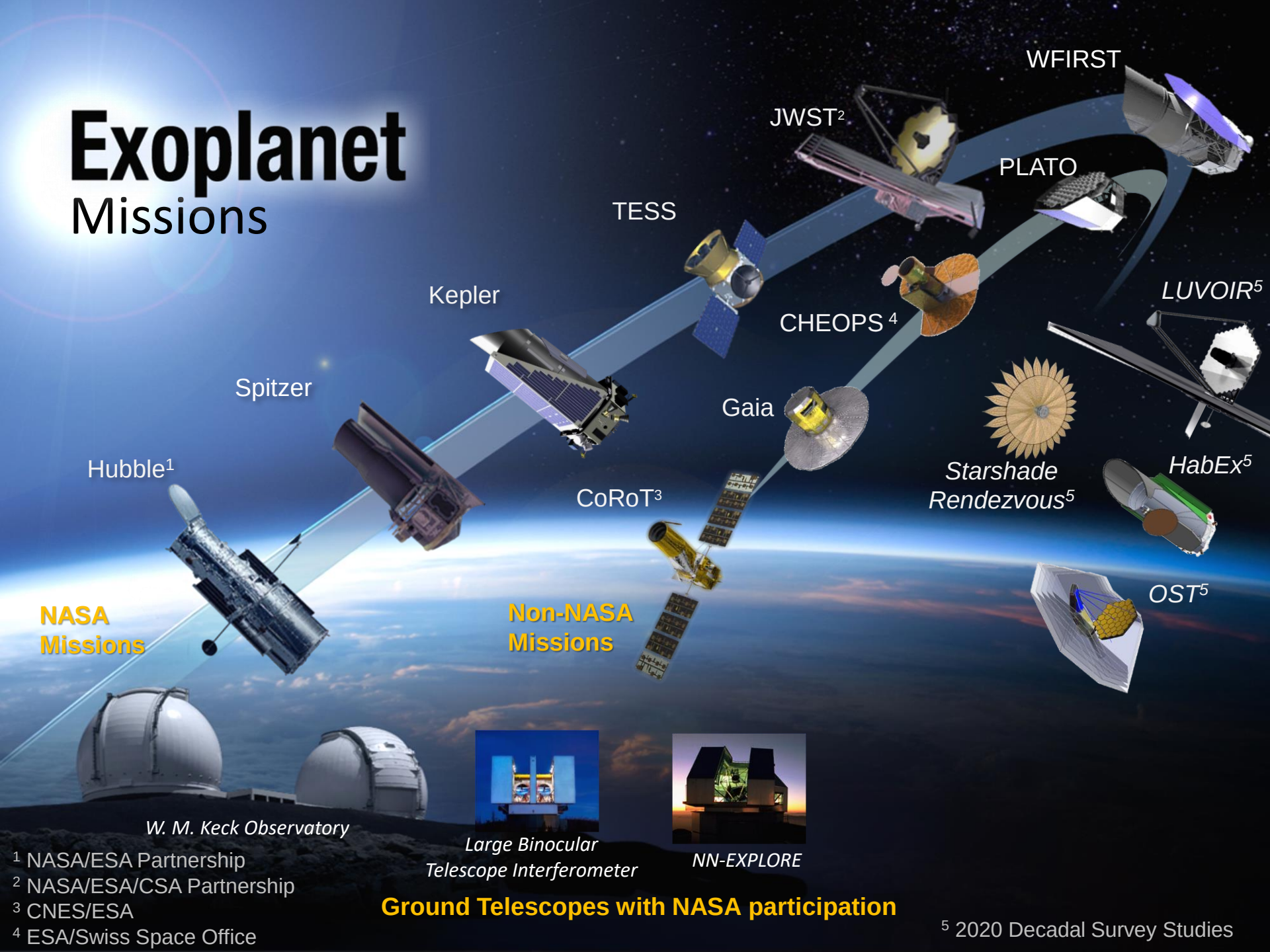


Inner Disk Deployment Trials

Starshade Optical Shield



Exoplanet Missions



[1] NASA/ESA Partnership
[2] NASA/ESA/CSA Partnership
[3] CNES/ESA
[4] ESA/Swiss Space Office

Ground Telescopes with NASA participation

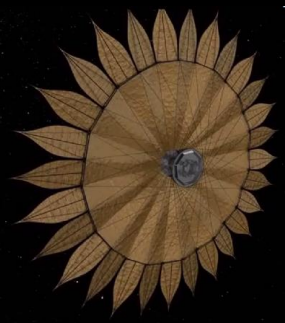
[5] 2020 Decadal Survey Studies

James Webb Space Telescope

Credit: NASA / GSFC

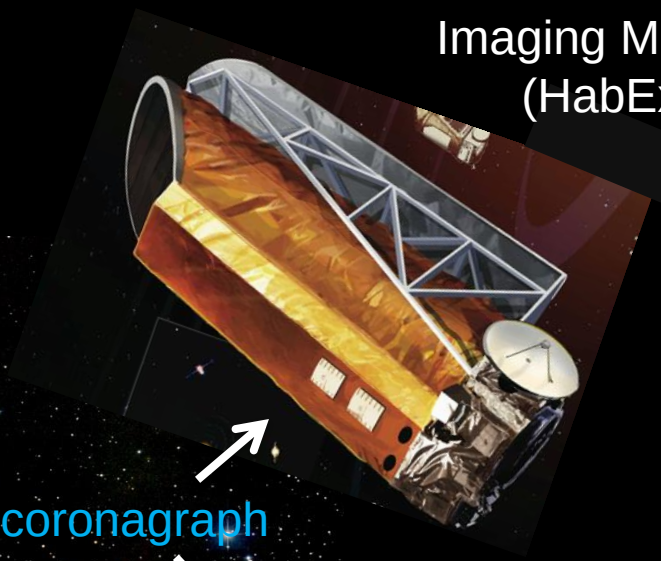
Possible New Worlds Exoplanet Telescopes

(mid 2030s)

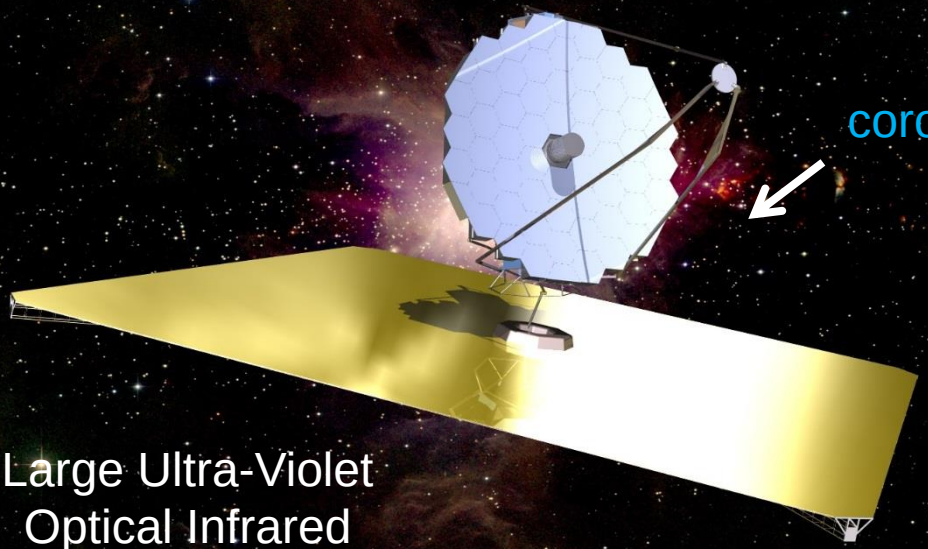


starshade

Habitable Exoplanet Imaging Mission (HabEx)



coronagraph

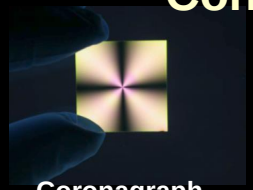


Large Ultra-Violet Optical Infrared Telescope (LUVOIR)

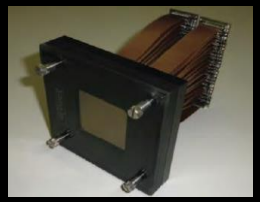
Origins Space Telescope (OST)

Coronagraph/Telescope Technology Needs

Contrast



Coronagraph architectures



Deformable mirrors

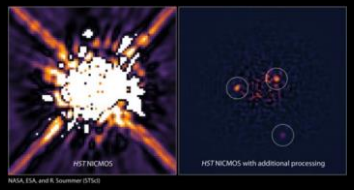
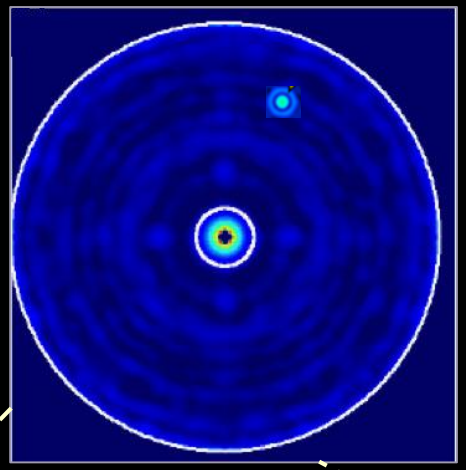
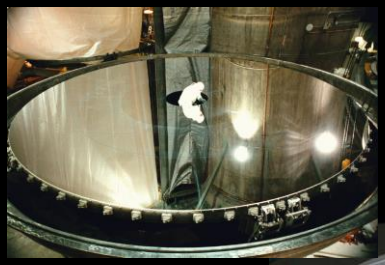


Image post-processing



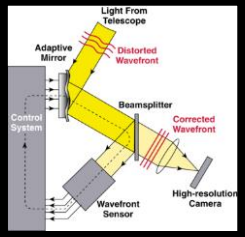
Angular Resolution



Large monolith

Segmented

Contrast Stability

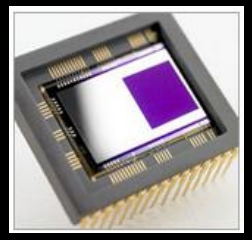


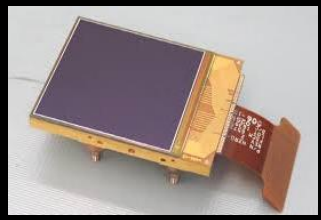
Wavefront sensing and control

Segment phasing and rigid body sensing and control

Telescope vibration sensing and control

Detection Sensitivity





Ultra-low noise visible and infrared detectors

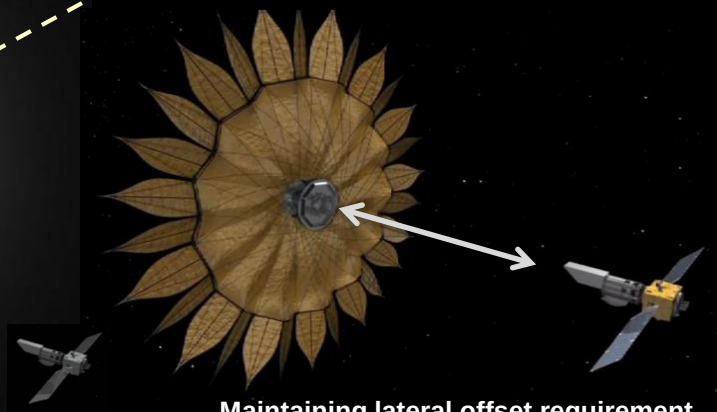
Starshade Technology Needs

1) Starlight Suppression

Suppressing scattered light off petal edges from off-axis Sunlight (S-2)

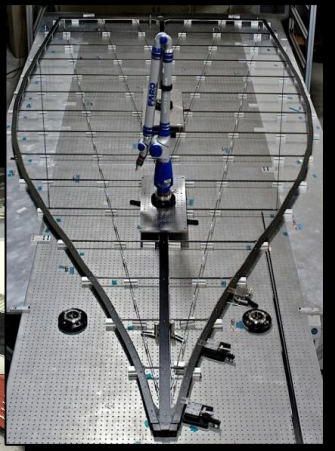
Suppressing diffracted light from on-axis starlight (S-1)

2) Formation Sensing and Control



Maintaining lateral offset requirement between the spacecrafts (S-3)

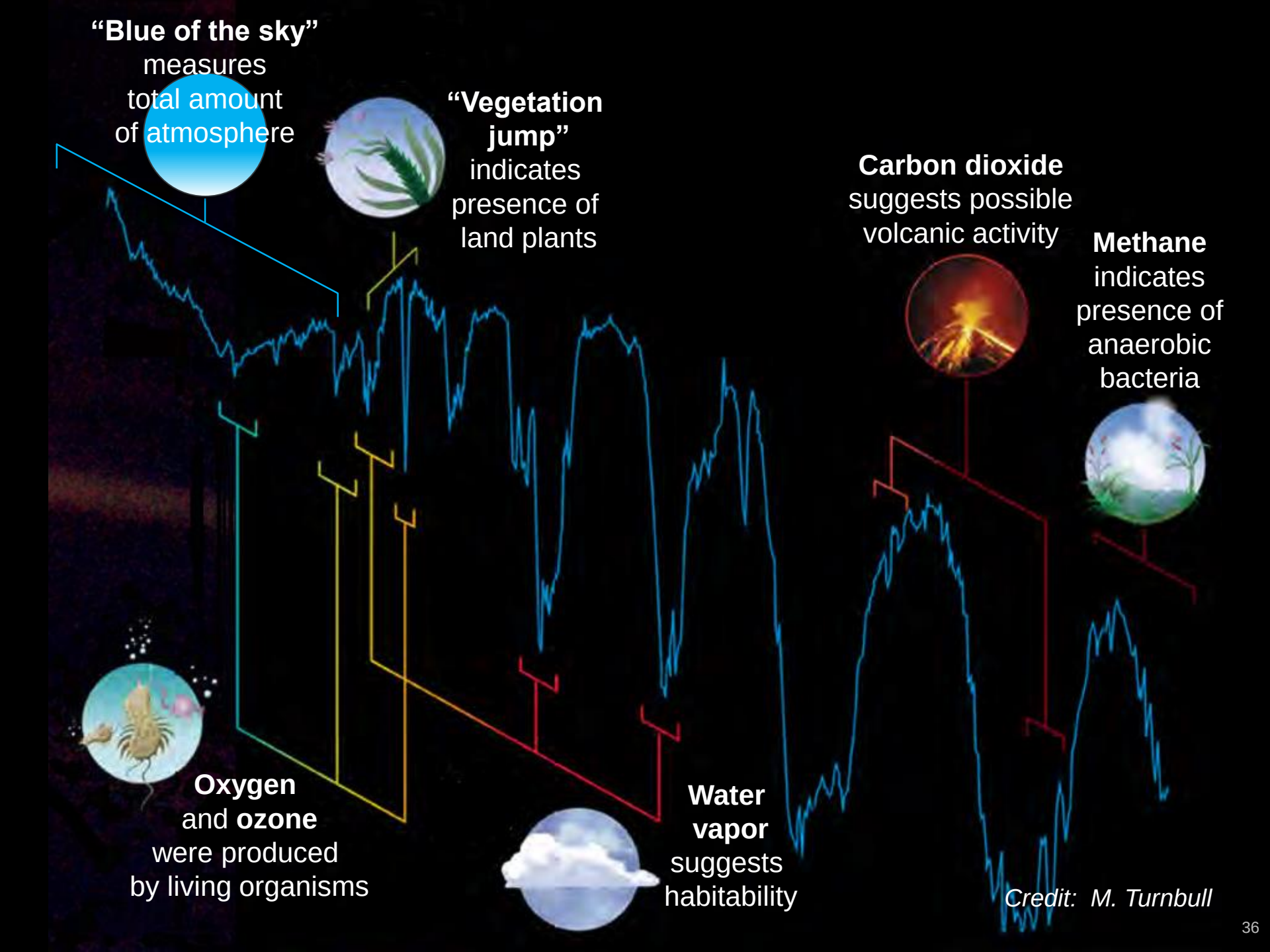
3) Deployment Accuracy and Shape Stability



Fabricating the petals to high accuracy (S-4)

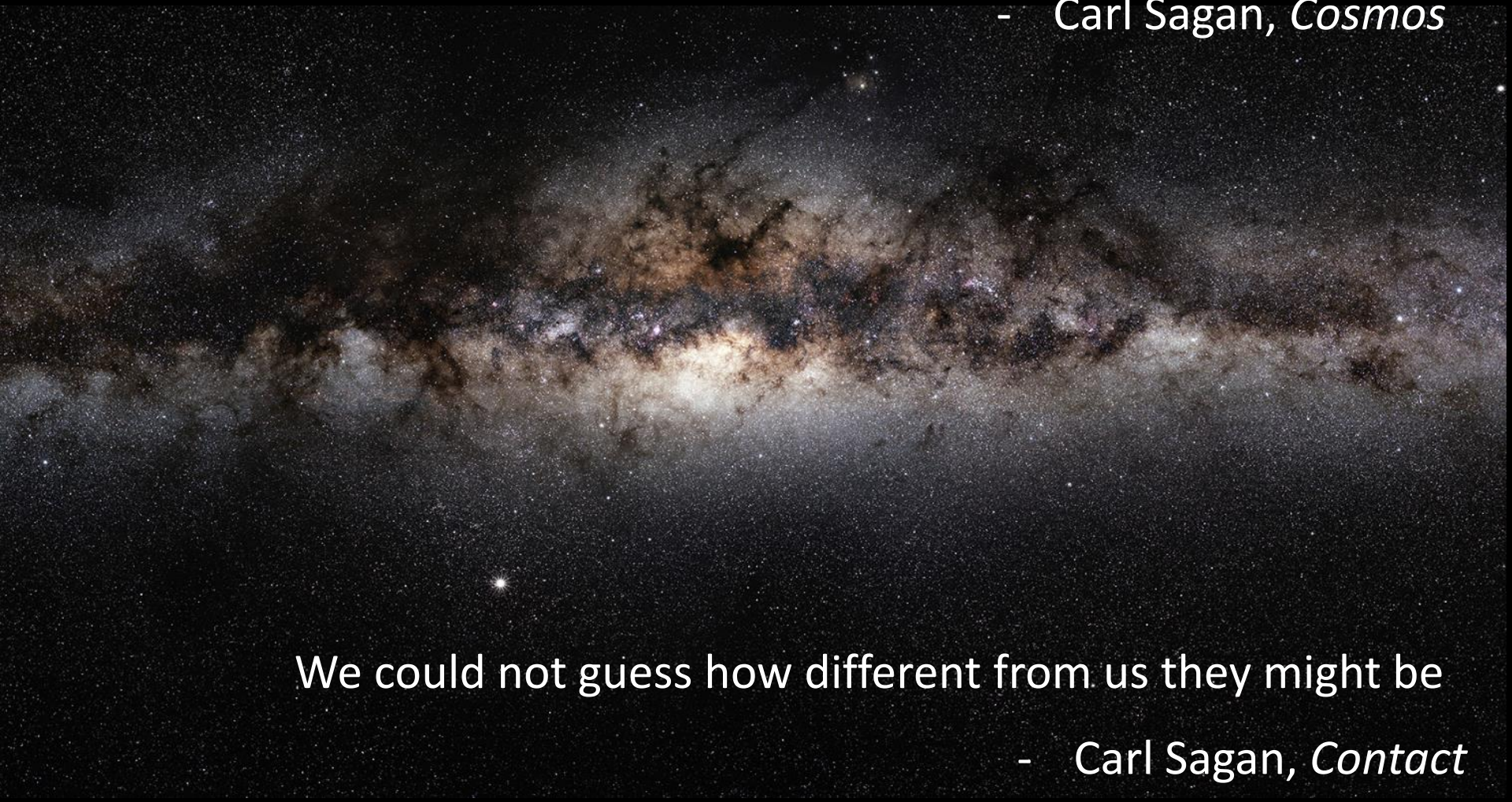
Positioning the petals to high accuracy, blocking on-axis starlight, maintaining overall shape on a highly stable structure (S-5)

S-# corresponds to ExEP Starshade Technology Gap number
http://exoplanets.nasa.gov/exep/technology/gap-lists


"Blue of the sky" measures total amount of atmosphere
"Vegetation jump" indicates presence of land plants
Carbon dioxide suggests possible volcanic activity
Methane indicates presence of anaerobic bacteria
Oxygen and ozone were produced by living organisms
Water vapor suggests habitability
Credit: M. Turnbull

And on those other worlds, are there beings who wonder as we do?

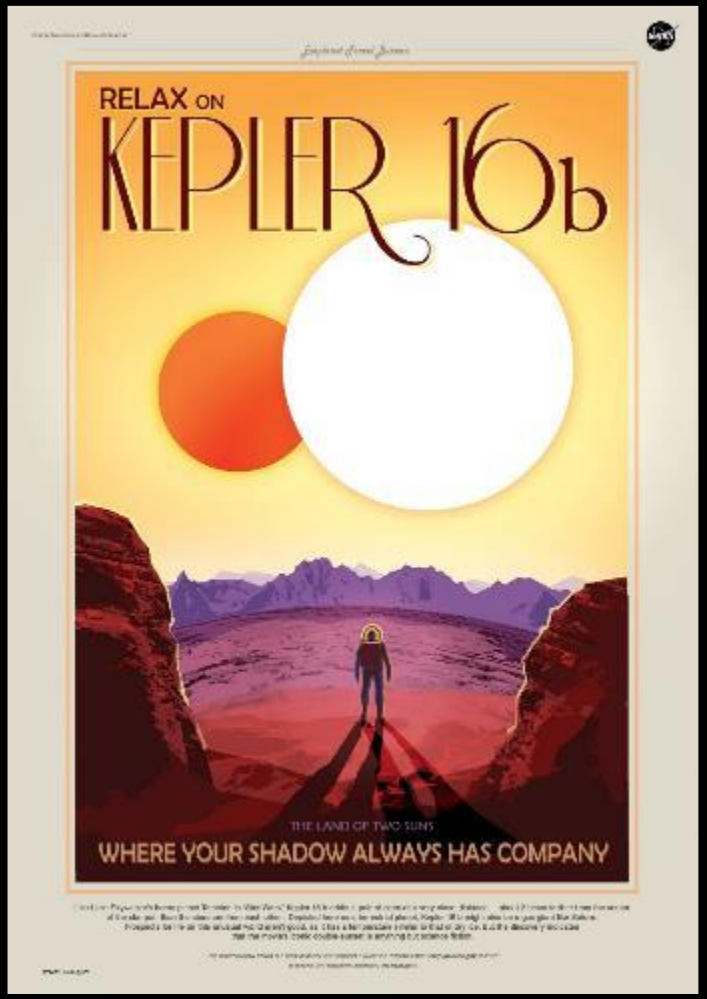
- Carl Sagan, *Cosmos*

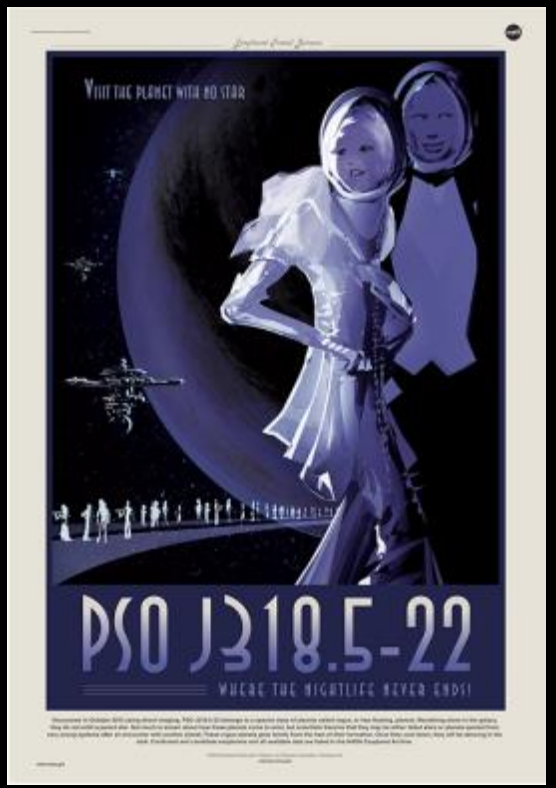


We could not guess how different from us they might be

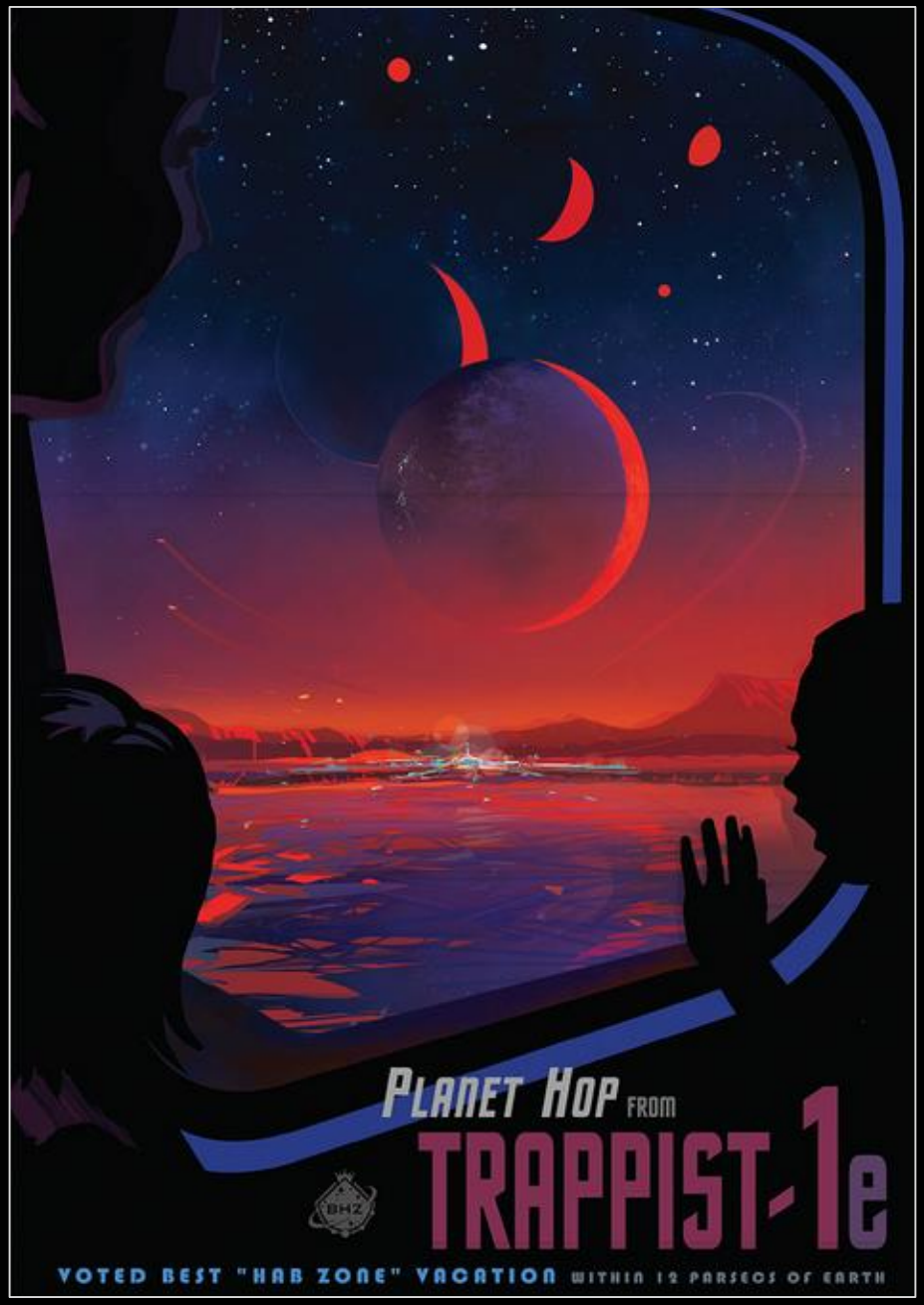
- Carl Sagan, *Contact*

Introducing: the Exoplanet Travel Bureau!





Exoplanet Travel Bureau



Inspiring our Own World

Caught in calm, perpetual twilight
Forty light years seems so far
Do you feel the same? Because I cannot breathe
Distant loving breaks my heart

I'm in love with TRAPPIST-1, though I'll never see your sun rise
You tore imagination a new hole
I'm in love with TRAPPIST-1, but your children have a dark side
Got a Hippocratic conscience to uphold

Aquarian sun
Give me TRAPPIST-1
As the feeling burns
And the dreaming yearns

IN ISOLATION

Artist concept of Kepler-16b

Jet Propulsion Laboratory
California Institute of Technology

exoplanets.nasa.gov

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Acknowledgements

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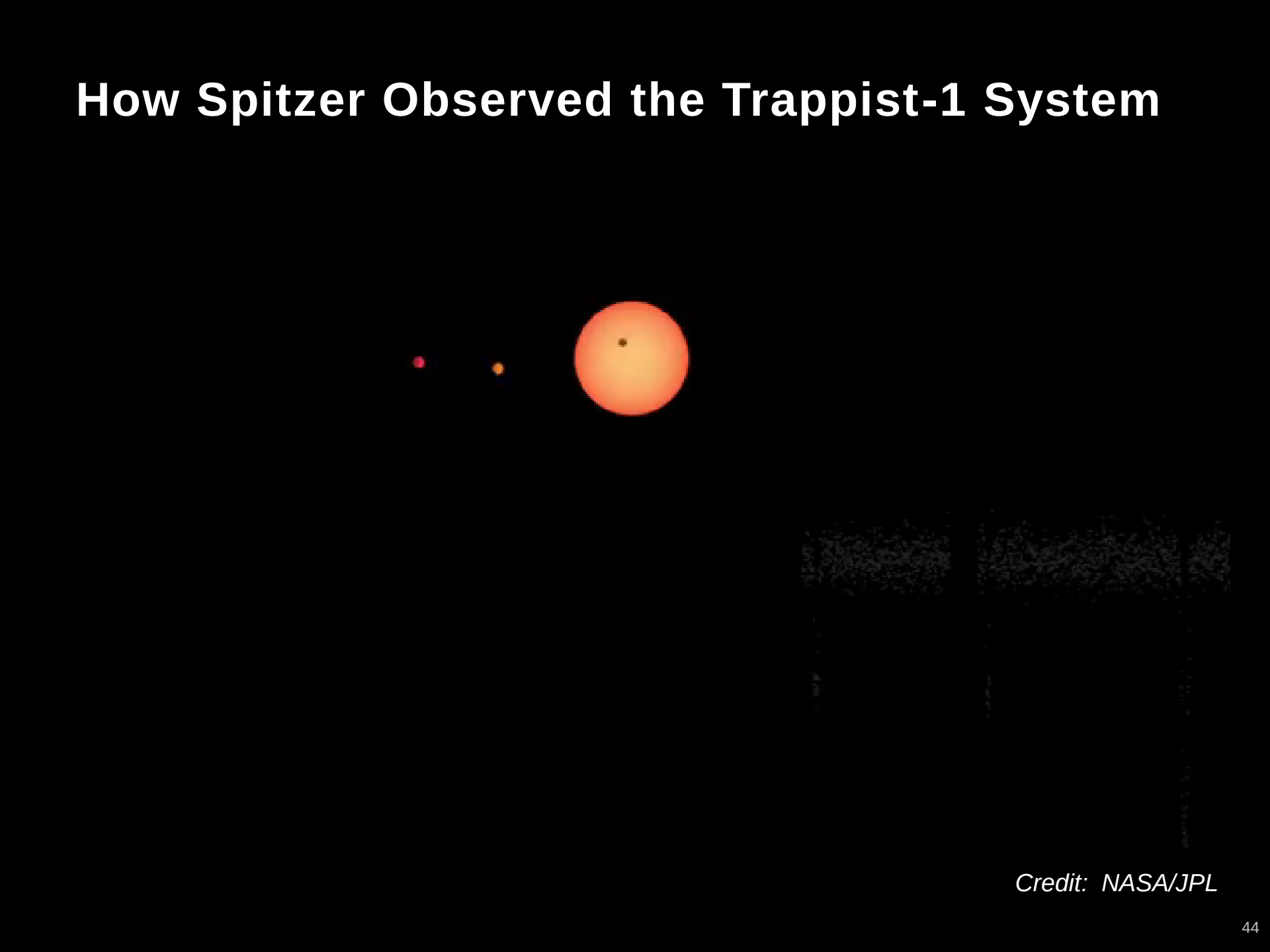
- Work was also carried out at NASA's
  - Goddard Space Flight Center
  - Ames Research Center
- Work was carried out as well under contracts with the National Aeronautics and Space Administration and
  - Princeton University
  - University of Arizona
  - Northrop Grumman Aerospace Systems
  - National Optical Astronomy Observatory (NOAO)
  - Massachusetts Institute of Technology
  - Pennsylvania State University
- Contributions from ExEP program leadership and staff gratefully acknowledged

How Spitzer Observed the Trappist-1 System



Credit: NASA/JPL